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VARIABLE GEOMETRY SHROUDED PROPELLER TEST PROGRAM

FINAL REPORT

VOLUME I

DATA ANALYSIS

8 May 1968

Prepared under Contract N00019-67-C-0087 for the Naval Air Systems Command, Department of the Navy by Hamilton Standard, Division of United Aircraft, Windsor Locks, Connecticut.

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VARIABLE GEOMETRY SHROUDED PROPELLER TEST PROGRAM

FINAL REPORT

VOLUME I

DATA ANALYSIS

8 May 1968

Work Period: December 1966 - May 1968

Prepared by Harry S. Wainauski Senior Analytical Engineer
Harry S. Wainauski

Approved by Carl Rohrbach Head of Aerodynamics and Hydrodynamics
Carl Rohrbach

W E Fortmann Chief of Technical Staff
William E. Fortmann

Al D. Croxall Chief Project Engineer
Al D. Croxall

Number of Pages 26

ABSTRACT

The shrouded propeller has long been recognized as an attractive means of augmenting propeller thrust at static and low-speed flight conditions. However, the shroud shape requirements for high static thrust are not compatible with the shape requirements for good high speed performance, and as a result, the current state-of-the-art shroud flight hardware designs are compromises between good high speed and static performance. This program presents test results on the extremes in shroud shape possible with a variable geometry shroud, thus permitting the attainment of optimum shape under static and cruise flight conditions. These data, together with the data from Contract NOw-64-0707-d (Reference 1) present the excursions in exit area ratio and lip shape possible with a variable geometry shroud and show that large performance gains can be made with such a shroud.

INDEX TO CONTENTS OF VOLUMES

TABLE OF CONTENTS

LIST OF FIGURES

FOREWORD

For convenience this report is divided into two volumes. The first volume contains a comparison of these new data with the data of Reference 1 for a typical hover and cruise flight condition and applies these data to the X-22 aircraft. Volume II contains a complete description of the test program with detailed model dimensions, test run schedule, and the test data.

INTRODUCTION

Modern high performance V/STOL aircraft require propulsive systems having high thrust to horsepower ratios in hover and at low foward airspeeds. Two classes of propeller propulsive systems have evolved for this class of aircraft; the large diameter free air propeller and the smaller diameter shrouded propeller. The shrouded propeller has the advantage of offering almost twice the static thrust of a free air propeller of the same diameter. The shrouded propeller has been the subject of significant research and development activity particularly in the recent past and is used on such vehicles as the X-22A VTOL aircraft and the "Hydroskimmer" ground effect machine.

The shroud designs utilized on these vehicles incorporate fixed geometry, that is, a fixed lip shape and exit area ratio. Unfortunately, these configurations represent compromise designs in that shrouds designed for high thrust at low speeds require a relatively large leading edge radius as well as a large exit area ratio to assure unseparated flow and to attain maximum shroud thrust. This "static" shroud configuration however, results in high drag at high speed cruise velocities. On the other hand, a shroud designed for good high speed cruise efficiency requires a small leading edge radius and a low exit area ratio to increase shroud critical Mach Number and to minimize shroud drag. This configuration, however, results in poor low speed performance because of flow separation from the small leading edge radius. Thus, present fixed geometry shroud designs reflect a compromise between high and low speed performance requirements.

Recognizing the potential of the shrouded propeller as an efficient propulsive device, the Naval Air Systems Command awarded contract NOw 64-0707-d to Hamilton Standard. The objectives of this contract were 1) to provide emperical test data over a sufficient range of shroud-propeller variabies from which a fixed geometry shroud configuration could be selected for a given operating condition and 2) to develop a reliable shrouded propeller performance prediction method utilizing the emperical test data to verify the method. The results of this work are presented in References 1 and 2.

Although that program covered a wide range of propeller and fixed geometry shroud shape variables, it did not include the extremes of area ratio and lip shape attainable with a variable geometry shroud. Accordingly, the Naval Air Systems Command awarded Hamilton Standard Contract N00019-67-C-0087 to conduct a wind tunnel test on shroud shapes representing those attainable with variable geometry. This program covers shrouds having area ratios of 1.4, 1.0 and 0.9 and with lip shapes suited to the intended flight operation of the individual shroud. These new data together with the data from the previous contract allows the performance capabilities of a variable geometry shroud to be estimated.

OBJECT

The objective of this program is to supplement the range of the test data obtained under Contract NOw-64-0707-d to those shroud geometries representative of variable geometry shrouds.

CONCLUSIONS

Based on an analysis of the test results, the following conclusions may be drawn:

1. The 1.4 area ratio shroud with the bell-mouth inlet provides up to 14% more net thrust than the 1.1 area ratio shroud of Reference 1.

2. The 1.0 and 0.9 area ratio high speed shrouds provide high cruise efficiencies with up to 30 per cent gain in net thrust over the 1.1 area ratio shroud of Reference 1.

3. A variable geometry shroud provides better overall aerodynamic performance at both static and cruise operating conditions than could be attained with a fixed geometry shroud.

4. The data from this contract are compatible and correlate well with the data from Reference 1.

RECOMMENDATIONS

Based on the test results, the following recommendations are made:

1. Further analytical work be done with the data from this program to investigate the aerodynamic performance of a variable geometry shroud for operating conditions other than those investigated in this report.

2. Mechanical design studies should be initiated to determine whether the indicated performance gains associated with a variable geometry shroud are off-set by the additional complexity of the hardware required to vary the shroud geometry.

3. Further testing be done to determine the effect of centerbody size and shape on the levels of performance.

DESCRIPTION

GENERAL DESCRIPTION OF TEST PROGRAM

In order to attain the objective of this program, three, 2.5 foot internal diameter shrouded propeller models were tested from near static conditions to a Mach number of 0.6 over an appropriate range of propeller power loadings and tip speeds. Of the shrouds investigated, one represented a low speed or static shroud design with a bell-mouth inlet and high exit area ratio while the remaining two shrouds represented high speed shroud designs with small leading edge radii and low exit area ratios. The shrouds were machined from forged aluminum rings and were instrumented so that shroud surface pressures could be measured.

The shroud shape variables investigated in this program were chosen to be compatible with those investigated under the test program of Reference 1. The resulting test data are thus an extension of those data to cover configurations representative of variable geometry shrouds. In particular, shrouds with area ratios of 1.4, 1.0, and 0.9 were tested. The cross-sectional shapes and dimensional data for all the shrouds and propellers are contained in Appendix 1 of Volume II. The 1.4 area ratio shroud incorporated a large bell-mouth inlet and was designed for static and low speed operation. The remaining two shrouds with area ratios of 1.0 and 0.9 were designed for high speed operation and incorporated small leading edge radii. The design and fabrication of these shrouds was handled and reported under separate funds. These shrouds along with the 1.1, 1.2 and 1.3 area ratio shrouds from Reference 1 cover the ranges of area ratio and lip shape attainable with a variable geometry shroud but simulated with fixed geometry model shroud hardware.

All three shrouds were tested in the United Aircraft Research Laboratories 18 foot low speed and 8 foot high speed wind tunnel test facility. Since it would not be reasonable for the low speed shroud configuration to be used at high flight speeds nor, conversely, the high speed shrouds to be used at low speeds, each shroud was tested at only those flight Mach numbers applicable to that shroud design. Accordingly, the low speed shroud design was tested over Mach numbers from near static up to 0.2 and the high speed shrouds from 0.2 up to 0.6. A complete description of this facility together with a detailed description of the test models, test equipment, location and size of test equipment is contained in Volume II of this report.

Each shroud-propeller model was tested on the propeller test rig over a sufficient range of blade angles and tip speeds to fully define the performance of each model. The test run schedule is presented in table II of Volume II. At each test point, shroud and propeller forces were measured through the use of an integral strain-gaged thrust and torque system in the propeller test rig for the propeller forces and an externally mounted strain-gaged force system for the shroud forces. The rotational speed of the propeller was measured by an EPUT meter and signal generator. Shroud inlet and exit velocities along with shroud surface pressures were measured independently of the force performance testing. This was done to eliminate any possible interference of the pressure tubing on the force measurements. A typical shroud installation is shown in figure 1.

All of these data were reduced to coefficient form and are presented in tables III through VI, Volume II of this report.

SHROUD DESIGN CONSIDERATIONS

LOW SPEED SHROUD

The selection of the shroud contours was based on both aerodynamic and mechanical design considerations. A mechanical design feasibility study was undertaken early in the program to determine the practical mechanical limits on shroud geometry variations by considering first a high speed shroud configuration and then seeing how that shroud configuration could be mechanically modified into a low speed shroud. This study considered such things as extendable leading and trailing edge segments and inflatable rubber boots to alter the shroud lip shape and exit area ratio for improved compatibility in cruise and take-off operation. Particular attention was given to the shroud internal surface shape to avoid irregularities and/or discontinuities which might disrupt the flow when the segments were extended or retracted. This study served to determine the practical interior and exterior shape characteristics for variable geometry shrouds.

Working within the framework established by the mechanical design study, the most desirable aerodynamic shapes were then selected. This selection was influenced by the results of the testing accomplished in Reference 1. It was determined from that testing that the internal lip shapes selected for hover conditions, and incorporated in those shroud designs, did not separate at static and low speed flight conditions. Therefore, that internal lip shape thickness distribution was chosen for the static shroud design and scaled to fit the desired shroud dimensions. Similarly, the test data from Reference 1 indicated that the diffuser on the 1.3 area ratio shroud was on the borderline of separating. That shroud incorporated a diffuser half angle of 11.98 degrees. Therefore, the diffuser half angle for the static shroud was lowered to 11 degrees to insure no separation and was lengthened four inches to obtain an area ratio of 1.4.

HIGH SPEED SHROUDS

The design of the high speed shrouds was based on knowledge of prior test results. Analysis of these data indicated that a shroud with a six percent thickness ratio airfoil section was best for low minimum drags and yet allowed a reasonable thickness for the shroud lip and structure. With a thickness ratio of six percent selected, the airfoil section data was searched to determine those sections which would give the lowest drags at the desired shroud exit area ratios. This search led to the selection of the NACA Series 65 airfoil thickness distribution on a circular arc mean camber line as being the most suitable. It was necessary to modify the camber line and thickness distribution slightly to obtain a linear internal diffuser shape. The cross-sectional shape of these shrouds as well as the exact dimensional data are contained in Volume II of this report. Photographs of the shrouds are shown in Figure 5, 6 and 7 of Volume II.

PROPELLERS

The testing in this program was initiated with the wide-tip propeller blades of Reference 1. These blades along with the 1.1 area ratio shroud of the referenced report were considered as the "basic" unit against which the performance of the other shroud-propeller units was compared. All of the low speed testing with the 1.4 area ratio shroud of this program was accomplished with these blades. However, early during the high speed testing, an inlet velocity rake failed and in passing through the propeller disc, destroyed these blades. It was necessary, therefore, to complete the test program with the narrow tip blades of Reference 1. Since the performance of these blades had been well established during the Reference 1 testing, this necessary change in propeller configuration did not in any way adversely affect the aims of this program. The characteristics of these blades is shown in figures I-6 and I-7 of Volume II of this report. A detailed description of the design philosophy behind these propellers, along with the performance of the propellers is contained in Volume I of Reference 1.

TEST EQUIPMENT

The experimental test program reported herein was conducted in the UAC subsonic wind tunnel test facility. The UAC subsonic wind tunnel, shown in Figure I of Volume II, is a single return, closed throat facility having either an 8 foot or an 18 foot octagonal test section. The 18 foot test section is part of the fixed tunnel structure while the 8 foot test section is a movable cart which inserts into the 18 foot section. The 18 foot section is a low speed facility that may be operated at velocities as high as 200 MPH. The 8 foot test section free from supports and models and with special wall inserts may be operated at Mach numbers as high as 0.95. However, for the present series of tests, shroud support system flexibility restricted the bulk of the testing to Mach numbers of 0.6 and less. Total pressure in the tunnel is atmospheric since the circuit is vented to the atmosphere in the return circuit through air exchangers which also allow a means of controlling stagnation temperature.

The propeller dynamometer consists of two variable-speed motors mounted in a tandem configuration within a slender streamlined body. The variable-speed motors are coupled together and provide a maximum torque of 330 ft-lbs through a speed range up to 12,000 rpm. The motors are mounted on hydrostatic bearings to provide restraint to all motion except axial motion along, and rotational motion about, the longitudinal axis of the dynamometer. These motions are restrained by load cells which measure thrust and torque of the model propeller. The rotational speed of the propeller is measured by a Berkley EPUT meter and signal generator. In this test a special nose was fabricated for the propeller test rig. This nose allowed the transfer of the propeller plane upstream and further away from the body of the test rig. In addition a non-rotating, sting-supported, Series 1 spinner was designed and fabricated for use directly in front of the rotating hub. The sting not only supports the spinner but also allowed a convenient means of routing the pressure loads from the inlet rake, upstream and out of the tunnel.

A strain-gaged shroud force measuring system consisting of Baldwin-Lima-Hamilton load cells was attached to the outside cowl of the propeller test rig. The exact details of the shroud force measuring system i.e., location of balances, direction of forces, etc. is contained in Volume II of this report. It should be pointed out that this shroud system is independent of the propeller force measuring system. Prior to the test program, extensive calibrations of the propeller and shroud force measuring systems were performed. The wind tunnel itself was calibrated with and without a shroud model to determine the effects of the shroud on tunnel velocity setting. These calibrations are discussed and explained in Volume II of this report.

The testing technique in both throats consisted of setting up a particular shroud-propeller model in the wind tunnel and setting the blade angle of the propeller. The velocity of the tunnel was then set to the desired level and the propeller rpm varied from 4000 rpm to the maximum desired for that configuration. At discrete rpm values during the run, the shroud and propeller force data were recorded. Running plots of these data were kept and any obviously out-of-line points were repeated. After the maximum rpm point had been reached, a new wind tunnel velocity was set and the rpm excursion repeated or the wind tunnel was shutdown and a new blade angle set and the process repeated. This procedure was repeated until all the blade angle-Mach number combinations for a particular configuration were completed and then a new shroud-propeller configuration was installed and tested in a similar manner. A complete run schedule is contained in table I of Volume II.

After all the force testing had been completed, the tubing required to measure the shroud pressures was installed, and shroud surface pressures and exit velocities were measured for a selected range of propeller blade angles, rotational speeds, and tunnel velocities. This method of testing was undertaken to insure that there would be no interference effects on the shroud force measurements from the considerable bundle of tubing required to measure the shroud surface pressures. This tubing was exposed to the propeller slipstream and could have caused an interference with the shroud chord force readings if the force and pressure data were taken simultaneously.

In addition to the tunnel and shroud and propeller test instrumentation, inlet velocity and exit total pressure rakes were fabricated and installed for certain pressure measurements. The inlet rakes sensed the distribution of velocity from the shroud centerbody to the inner surface of the shroud near the shroud lip and directly in front of the propeller plane of rotation. The exit rake consisted of 25 Kiel probes located at the shroud trailing edge and extending radially from the centerbody to the shroud exit. This rake sensed the increase or decrease in total pressure at the shroud surface.

Also utilized was a remotely operated United Sensor and Control Corp DAT-250 traversing probe which traversed radially outward from the shroud centerbody at the shroud exit. This probe sensed yaw and pitch angles, total and static pressures and temperature. All of these quantities were measured at sufficient radial locations across the shroud exit to completely define the flow at this location.

The location of this instrumentation is shown in Volume II, Appendix II.

MODEL CONSTRUCTION

The shrouds used in this program were machined from solid aluminum rings. This method of design was chosen because of the test experience acquired in conducting the testing of Reference 1. In that testing, severe damage was done to the blades when shroud fasteners worked loose and fell into the propeller. These new shrouds were designed to have as few pieces as possible and the design concept was proven out as no difficulties were experienced with any of these aluminum shrouds.

The model propellers used were of solid aluminum construction and selected from these previously tested in the program of Reference 1.

ACCURACY OF DATA

Two general categories of data were obtained in this test. The first of these is the force data in which the loads and forces generated by the shroud and propeller were measured with strain-gaged load cells. The second category is the pressure data. These pressure data can be broken down still further into pressure data obtained with rakes and the traversing probe and static pressure distributions on the shroud surface. A complete listing of all of these data is presented in tables III through VII in Volume II.

The accuracy of these data has been analyzed by United Aircraft Research Laboratories and is presented on pages 7 and 8 of Volume II.

RESULTS AND DISCUSSION

INTRODUCTION

The scope of the analysis covered by this program is limited to presenting a correlation between the data of Reference 1 and that of the present test at a typical hover and high speed cruise condition. This represents only a very small sampling of the data and it is strongly recommended that additional data analysis be undertaken to more fully explore the potential of a variable geometry shroud.

In a later section, these data will be applied to some typical operating conditions for the Bell X-22A. It will be shown that, theoretically, significant improvements can be made in both the high speed and take-off performance of that aircraft.

DATA PRESENTATION

In Reference 1, area ratios of 1.1, 1.2 and 1.3 were tested over a wide range of free stream Mach numbers and propeller power loadings. The shroud with the 1.1 area ratio diffuser and wide tip propeller blade was selected as the basic or "yardstick" shroud against which the performance of the other shroud-propeller variables was compared. This plan will be retained for this report. Figure 2 and 3 illustrate the performance of the shrouds of Reference 1 and the shrouds of the present test program. These plots are in terms of net thrust per horsepower versus power loading for values of constant tip speed. Net thrust is defined as the combined thrust of the shroud and the propeller.

LOW SPEED SHROUDS

The performance of the 1.4 area ratio shroud as compared to the shrouds of Reference 1 is shown in figure 2 and summarized in figure 4. As can be seen, the static performance of the low speed or 1.4 area ratio shroud is higher on the average than any of the shrouds of Reference 1. However, the rate of change of net thrust with area ratio is leveling off with apparently little more to be gained by increasing the area ratio beyond 1.4. The exact reason for the cross-over of the intermediate power loading line of figure 4 is not clear as simple momentum theory would indicate a uniform increase proportional to the cube root of the area ratio. Nevertheless, this figure does indicate the general trend of increasing net thrust with area ratio.

The distribution of static pressure on the inner surface of this shroud is shown in figure 5. The high negative pressure coefficients on the shroud leading edge indicate that most of the thrust produced by the shroud is generated in the lip area, as would be expected, and emphasizes the importance of proper lip design to prevent flow separation in that region which would cause a large loss in performance. A study of the force data for this point indicates that the ratio of net thrust to propeller thrust is 2.36 at a free stream Mach number of 0.0279. This indicates that the shroud contribution is more than 50 per cent of the total thrust of the unit. It should be pointed out that a V = 0 conditions, this ratio would be larger.

HIGH SPEED SHROUDS

Similarly, the summary of the performance of the high speed shrouds at one representative cruise Mach number and tip speed is indicated in figure 4. This figure shows the significant gain in performance, an average of 19% over the 1.1 area ratio shroud, that can be gained by decreasing the area ratio to 0.9 at high flight Mach numbers. However, the low area ratio shrouds, incorporating this lip, cannot sustain a high suction load in the lip region as is graphically illustrated in Figure 6. This figure shows the distribution of static pressure on the internal surface of the 1.0 area ratio shroud. Whereas the 1.1 area ratio shroud of Reference 1 had negative pressure coefficients in the lip region, the 1.0 area ratio shroud shows slightly positive values in this region. Review of the force test data for this point indicates that the ratio of net thrust to propeller thrust is 0.99. Thus, there is a drag on the shroud rather than a thrust which is substantiated by the positive values of pressure coefficient.

The foregoing is a brief analysis of the test data. The scope of this program does not allow a more detailed analysis but it is apparent that the data are consistent with those of Reference 1 and together with the latter data can effectively define the performance of a variable geometry shroud. As stated previously, it is strongly recommended that a more detailed analysis of those data be made to determine the full potential of a variable geometry shroud.

VELOCITY DATA

Prior to the start of the performance testing of the shrouds, a velocity survey of the bare propeller test rig was made using the instrumentation discussed and illustrated in appendix IV of Volume II. Two primary observations were made with this instrumentation

1. A slight variation of static pressure with axial distance exists as shown in figure 7.

2. A significant radial velocity decrement exists at the shroud exit plane as shown in figure 8.

The axial static pressure variation results in a small shroud drag increment which should be added to the basic force data to correct for this variation. This has been done for all the data contained in Volume II. It is more difficult to correct for the radial distribution of velocity at the shroud exit as it primarily affects the propeller performance. The affect of a shroud is to move this velocity distribution from the shroud exit to the propeller plane. Consequently, the propeller operates in a reduced velocity field with resulting apparent high efficiency levels. Figure 9 illustrates the performance of the propeller with and without a shroud. As can be seen, the addition of the shroud results in significantly higher propeller efficiencies than those attained using the propeller alone. However, propeller efficiencies obtained in this manner are apparent efficiencies, representing only the forces on the propeller blades. A drag on the centerbody (or nacelle or body behind the propeller) partially offsets the apparent improvement in propeller efficiency. However, there may be a real, or net gain in propeller efficiency over a propeller operating in a higher speed velocity field due to a reduction of compressibility losses associated with the lower local Mach numbers at the blade sections in the reduced velocity field.

An experimental assessment of the effect of centerbody size and location on shroud-propeller performance is beyond the original intent of the scope of this program. However, to obtain an indication of the effect of centerbody size on performance, the velocity data obtained during the rig flow field investigation, as contained in appendix IV of Volume II, was incorporated in an analytical study undertaken in connection with the calculation method developed in Reference 2. This analytical method will account for the effect of centerbody location and shape on both propeller and shroud performance. Using this analytical method, comparisions were made between calculated and measured performance data for two centerbody configurations. The first centerbody configuration was the shape of the propeller test rig as used in this test and the second configuration consisted of a theoretical, slender, cylindrical body of the same diameter as the propeller hub and extending straight back from the propeller hub beyond the trailing edge of the shroud.

The results of the analytical study indicate that the shape of the centerbody as used in this test significantly increases the thrust coefficient of the propeller for a given power loading. However, the calculated incremental variation of performance with area ratio when compared to measured test data did not appreciably vary with centerbody configuration. Thus, it appears that the prime effect of the shape of the centerbody is to raise the measured performance levels. It should be pointed out that the method of Reference 2 does not precisely predict the absolute values of net thrust due to limiting assumptions in both the invicid net thrust and shroud drag computational procedures. However, incremental trends between shroud-propeller configurations are predictable.

In order to emperically adjust the levels of the data of this report and those of Reference 1 for centerbody effects, additional testing beyond the scope of this program is required. This can be done with the hardware from this program and graduated buildups on the surface of the present propeller test rig. It is recommended that such a program be given strong consideration.

APPLICATION

Similar to Reference 1, these data can be applied to some representative flight conditions for the X-22A. The table below, showing the percentage increase in net thrust, indicates three conditions taken from the X-22A flight spectrum.

Shape Change	Present X-22A	Change To	Condition: Hover 761 HP, 2590 rpm	225 Kts 600 SHP 1840 rpm	340 Kts 1328 BHP 2220 rpm
Area Ratio (Increase)	1.17	1.4	8.7 %	---	---
Area Ratio (Decrease)	1.17	1.0	---	19.2 %	15.8 %
Area Ratio (Decrease)	1.17	0.9	---	38.0 %	30.5 %

As can be seen, significant gains are indicated for this aircraft at both ends of the flight spectrum with a variable geometry shroud. No consideration has been given in the comparison as to whether this change is structurally feasible with the present aircraft. However, the concept does look promising and more detailed aerodynamic and mechanical design studies must be undertaken to see if these benefits may be realized in a practical application.

LIST OF SYMBOLS, SUBSCRIPTS AND DEFINITIONS

AR	Area ratio; the ratio of the open area at the shroud exit to the open area at the propeller plane.
BHP	Horsepower input to the propeller.
C_p	Pressure coefficient, $\dfrac{P_l - P_\infty}{1/2\ \rho V_\infty^2}$
D	Propeller diameter, ft.
J	Advance Ratio, $\dfrac{V_\infty}{nD}$
n	Propeller speed, RPS
M	Mach number
P	Static pressure, PSF
T	Thrust, lbs.
V	Velocity, FPS
η	Propeller efficiency, $= \dfrac{T_p \times V_\infty}{BHP}$
ρ	Air density, $\dfrac{\text{lbs - sec}^2}{\text{ft}^4}$

Subscripts

o	Sea level, standard day conditions
l	Local
p	Propeller
∞	Free stream conditions

REFERENCES

1. Black, D. and Wainauski, H.S.: Hamilton Standard Shrouded Propeller Test Program, Hamilton Standard Report HSER 4348; May, 1967, Volume I. (This report consists of four volumes; Volume I is the data analysis. Volumes II through IV contain the test data).

2. Worobel, R. and Peracchio, A.A.: Hamilton Standard Shrouded Propeller Test Program, Method Development, Hamilton Standard Report HSER 4776; January, 1968; Volume I. (This report consists of two volumes; Volume I is the method development and Volume II is the computer program).

FIGURE AND CURVES

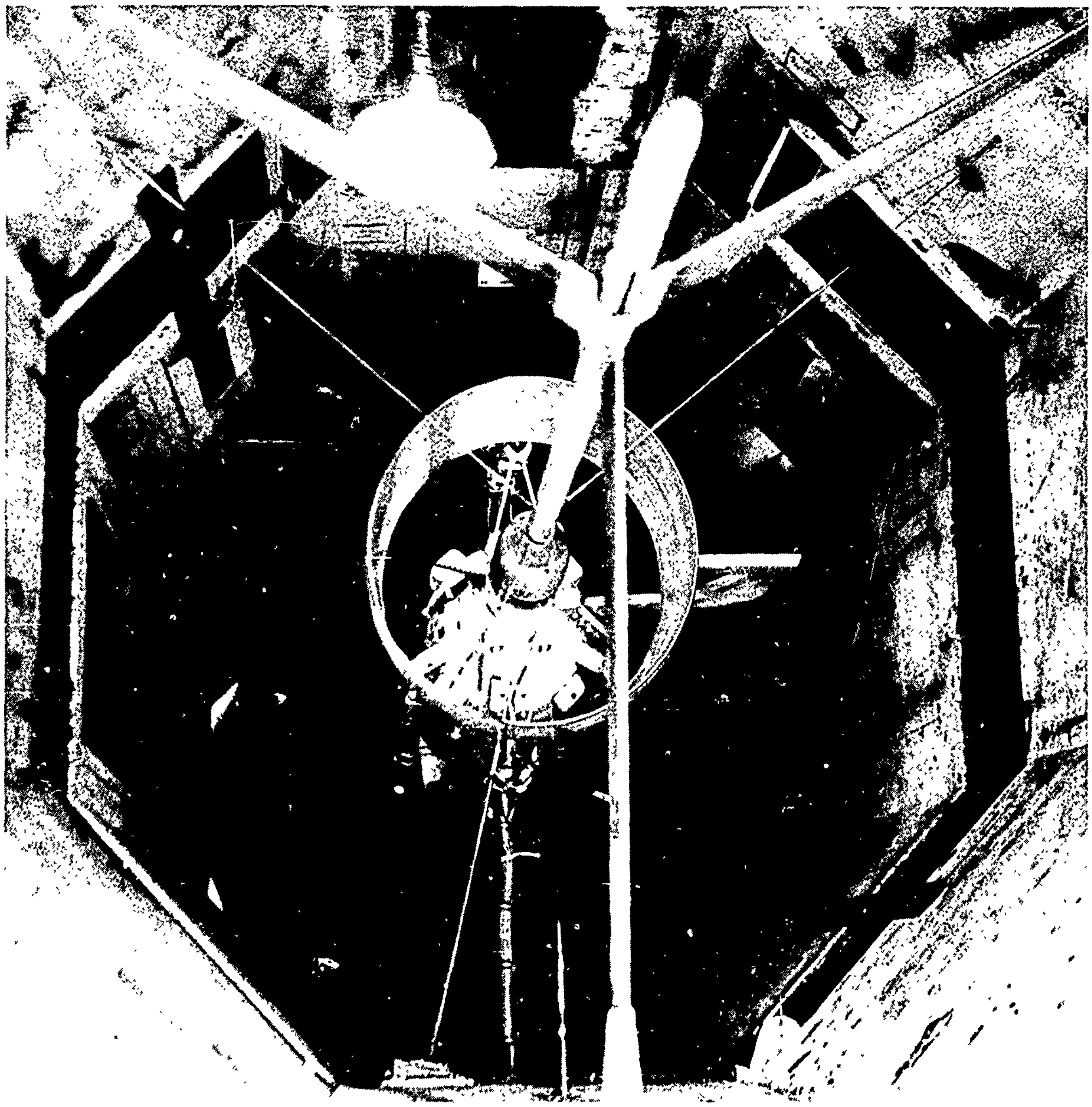

Figure 1. View of the Shroud Installed in the 8 Foot Test Section

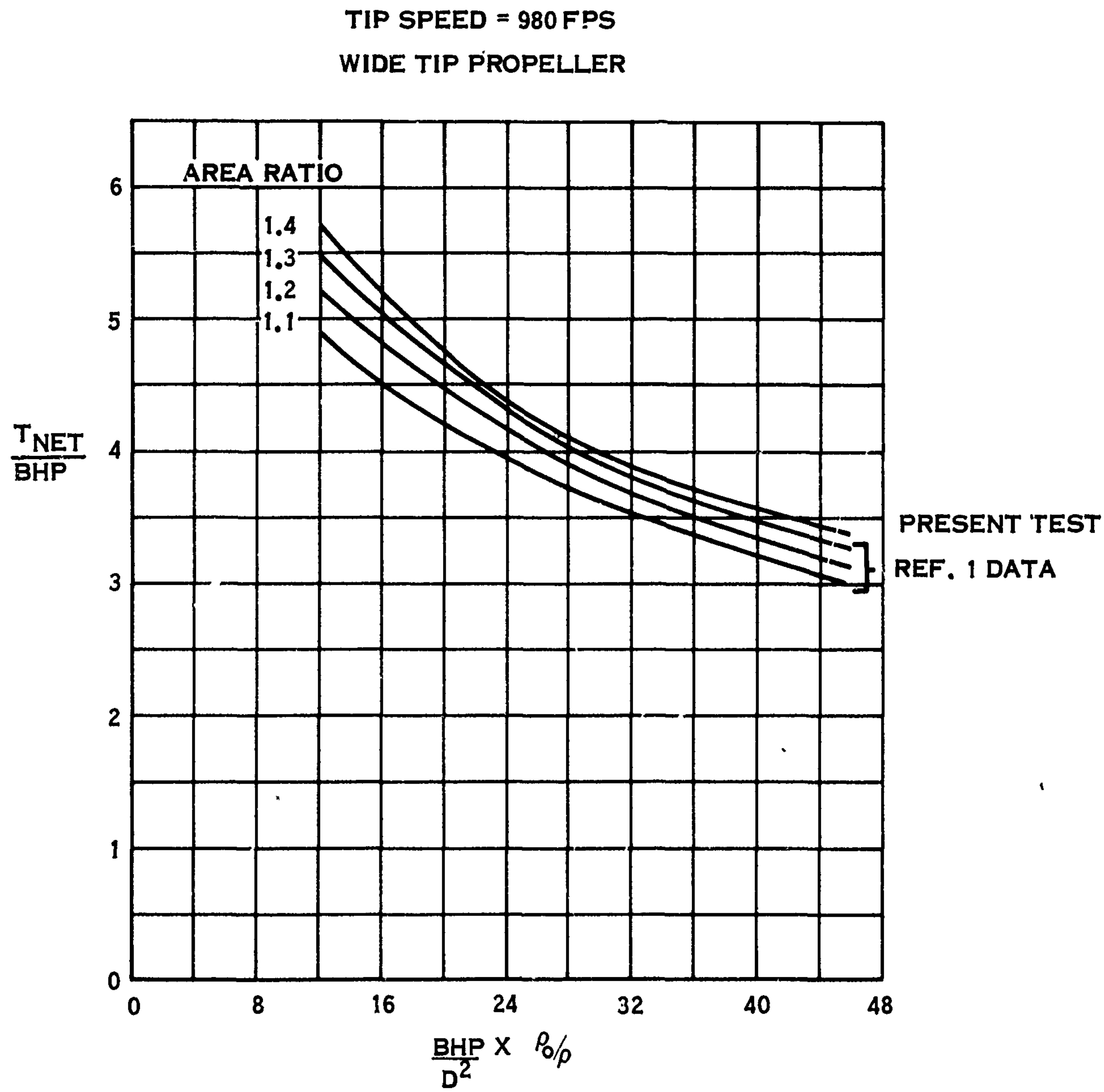

Figure 2. Variation of Net Thrust per Horsepower with Power Loading (Mach = 0)

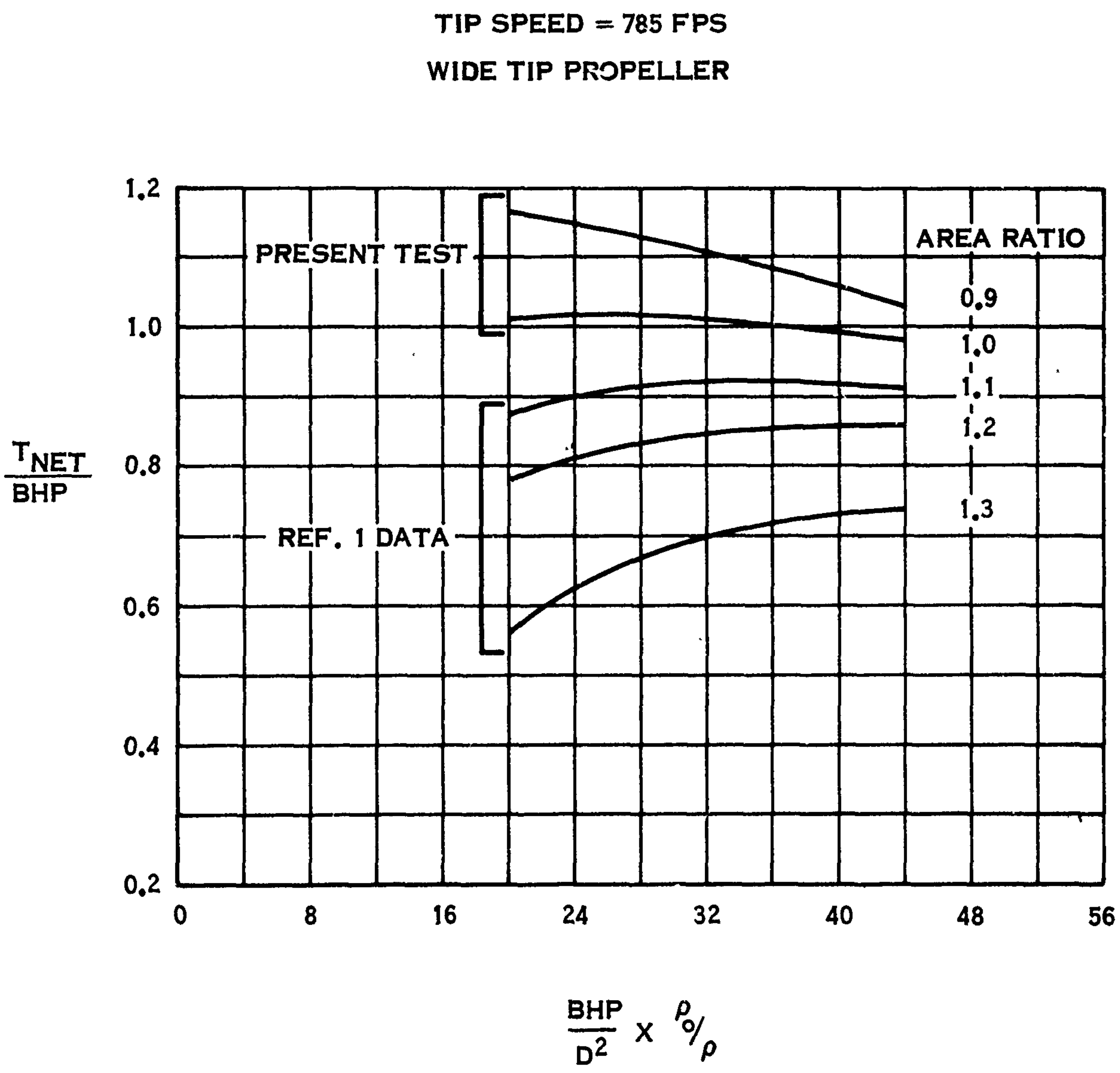

Figure 3. Variation of Net Thrust with Power Loading (Mach = 0.4)

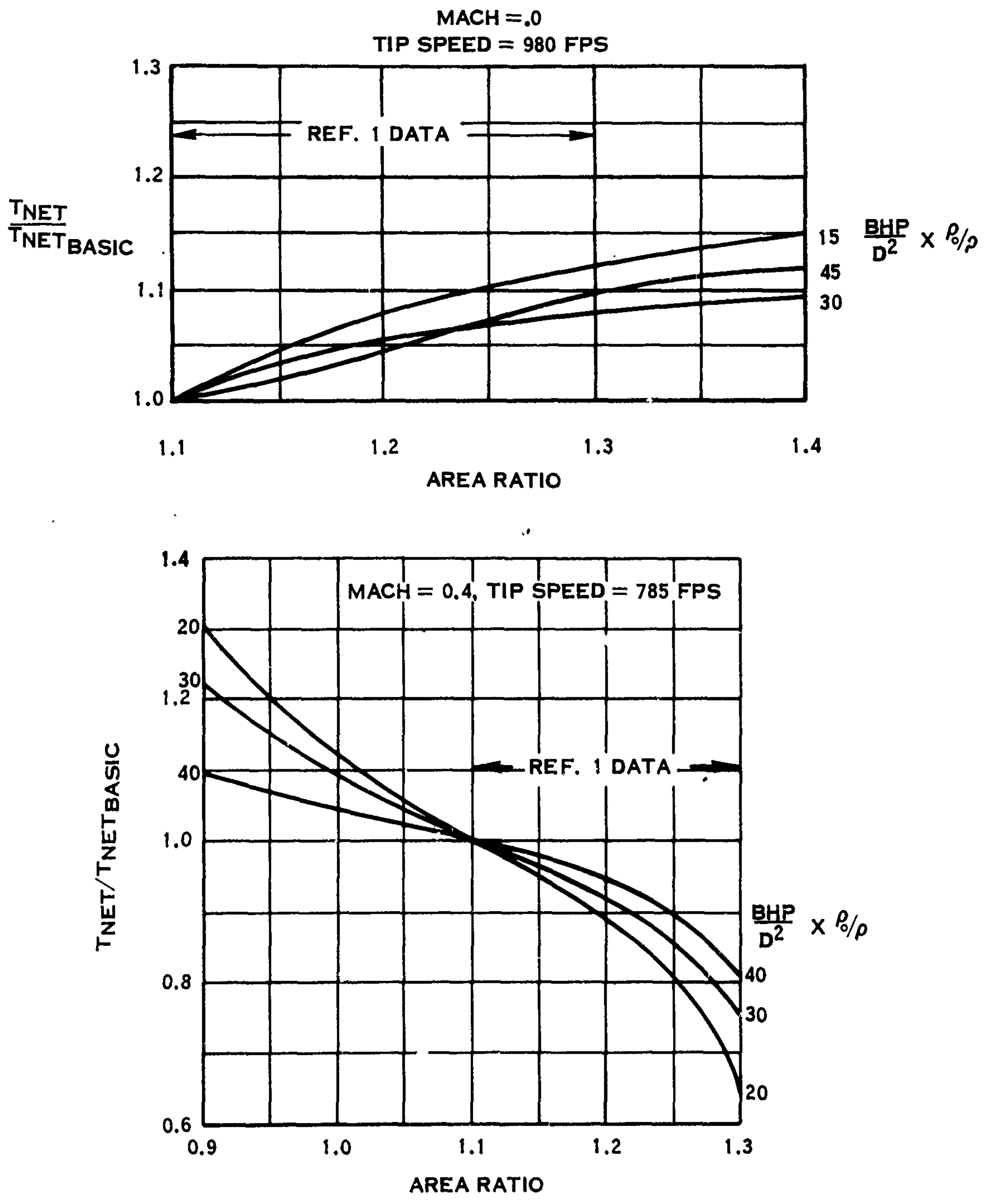

Figure 4. Effect of Area Ratio on Net Thrust

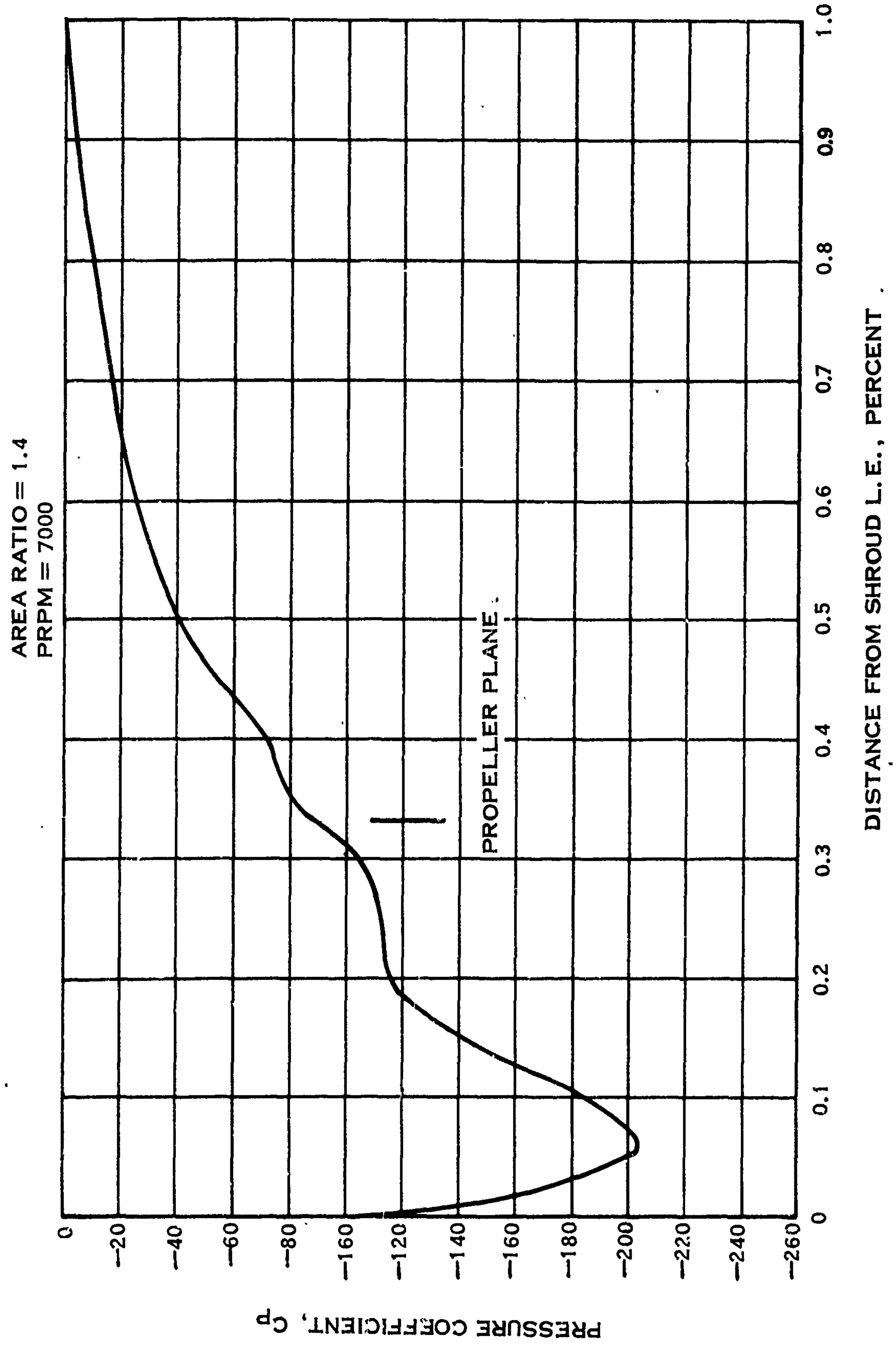

Figure 5. Shroud Internal Static Pressure Distribution (Mach = 0.0279)

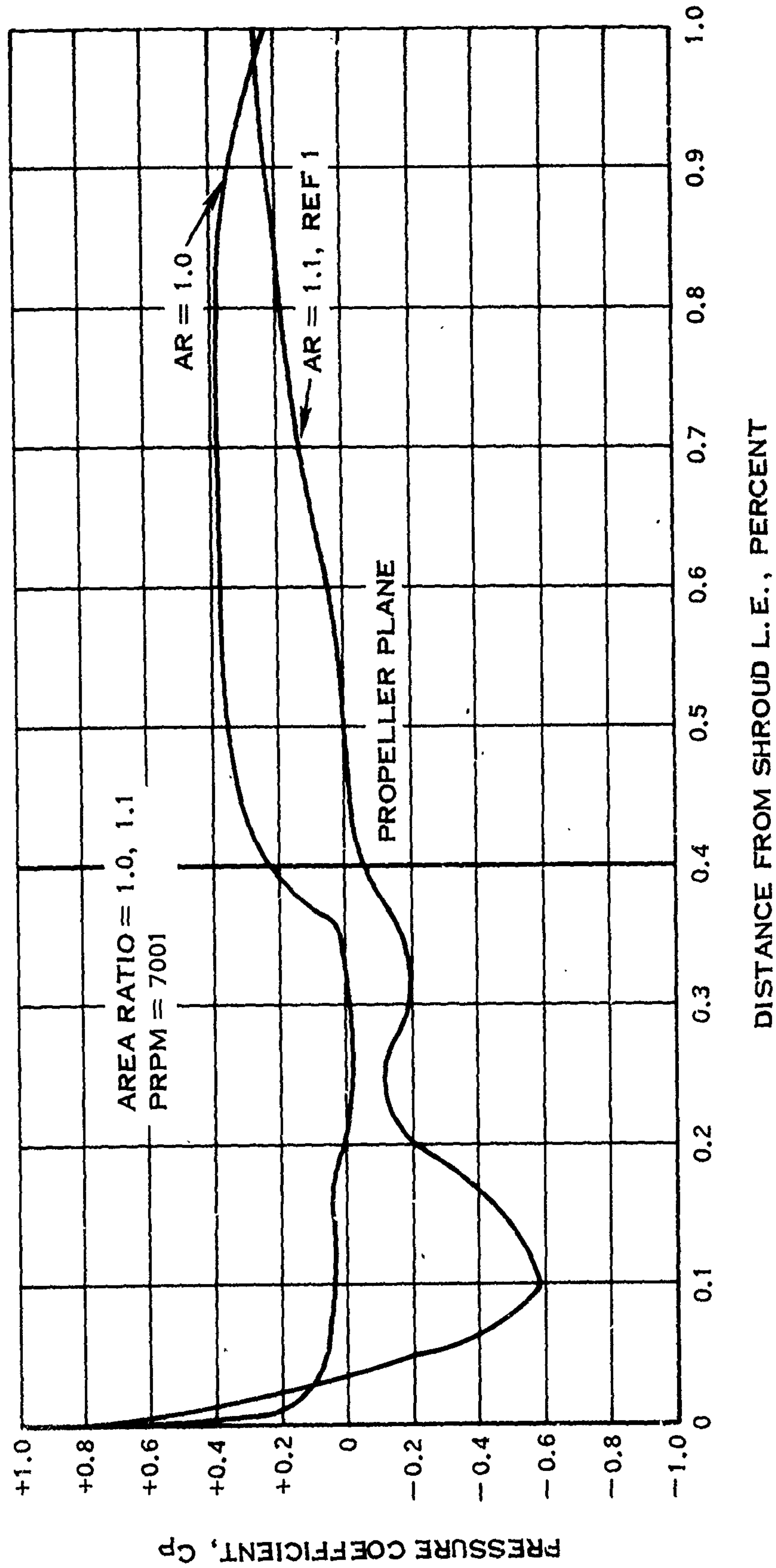

Figure 6. Shroud Internal Pressure Distribution (Mach = 0.4)

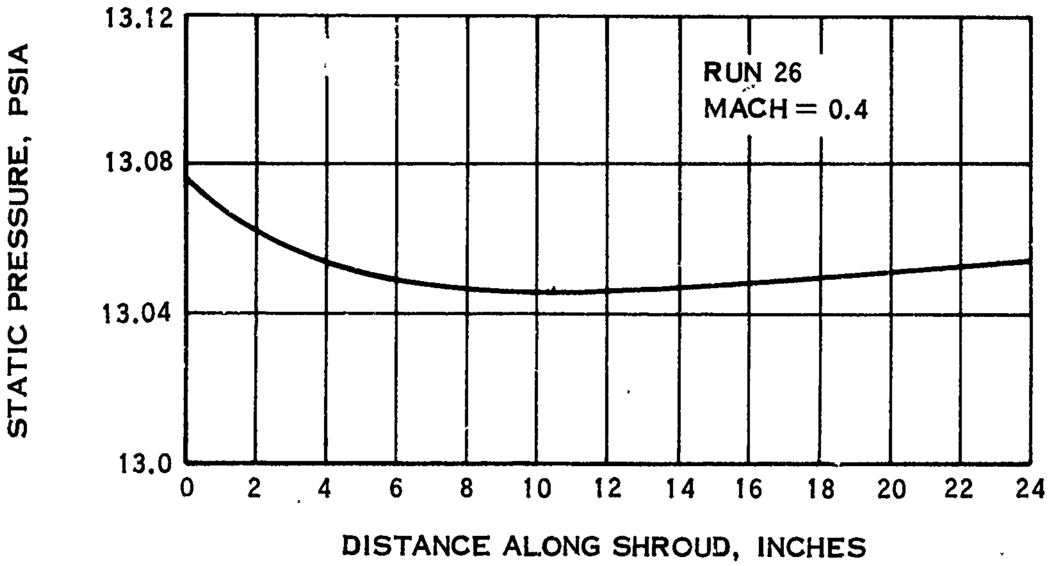

Figure 7. Typical Variation of Axial Static Pressure

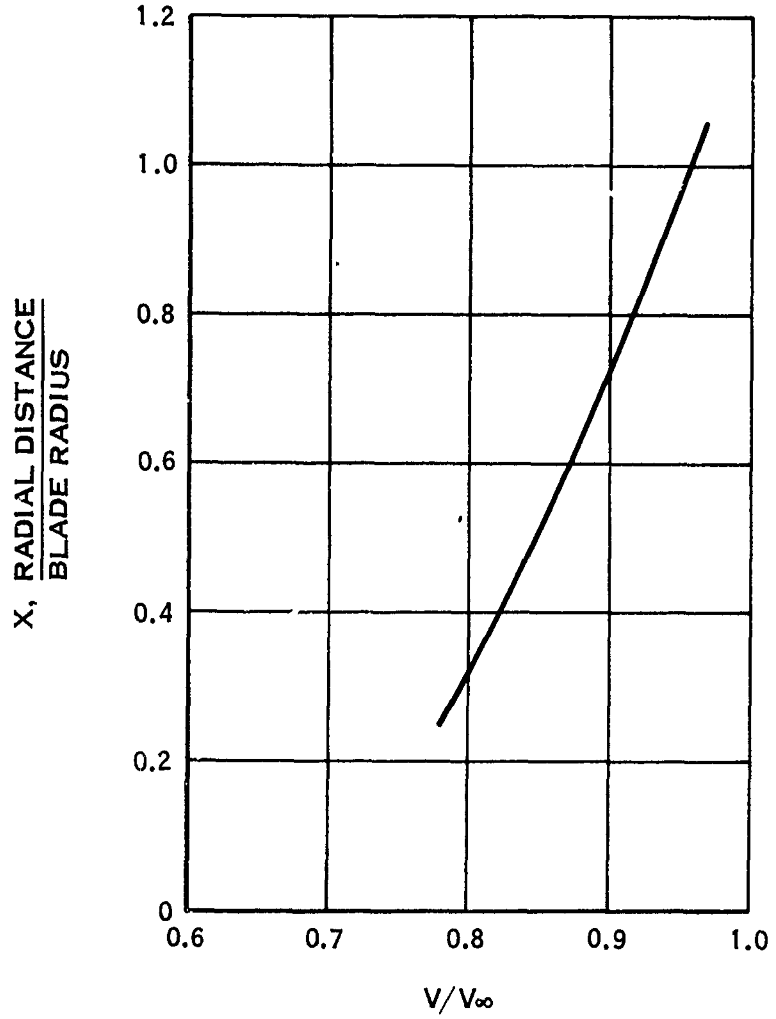

Figure 8. Typical Variation of Velocity at the Shroud Exit Plane Due to Propeller Test Rig Shape

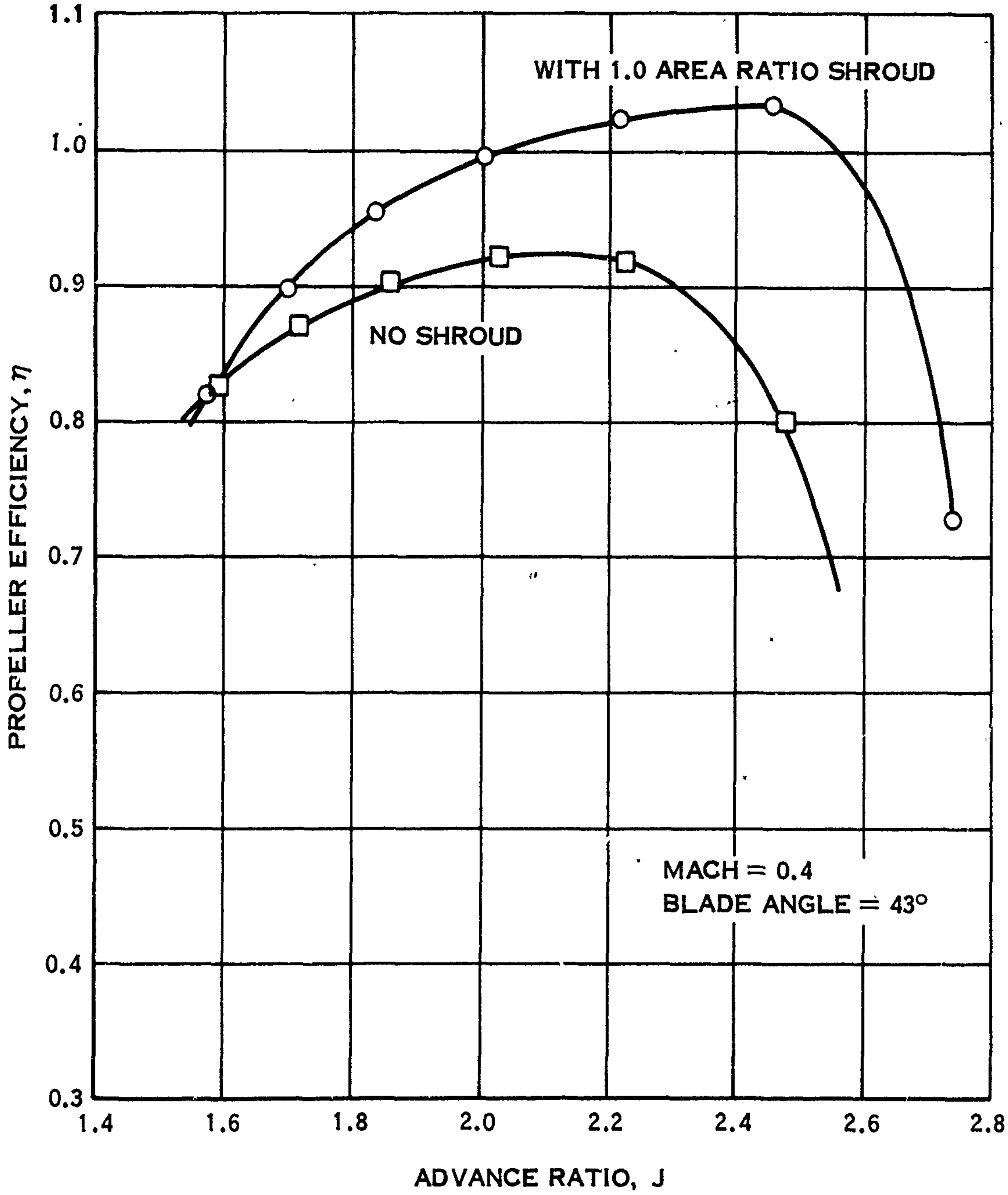

Figure 9. Performance of Propeller with and without a Shroud

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command, Department of the Navy

13. ABSTRACT

The shrouded propeller has long been recognized as an attractive means of augmenting propeller thrust at static and low-speed flight conditions. However, the shroud shape requirements for high static thrust are not compatible with the shape requirements for good high speed performance, and as a result, the current state-of-the-art shroud flight hardware designs are compromises between good high speed and static performance. This program presents test results on the extremes in shroud shape possible with a variable geometry shroud and thus permit the attainment of optimum shape under static and cruise flight conditions. These data, together with the data from Contract NOw-64-0707-d (Reference 1) present the excursions in exit area ratio and lip shape possible with a variable geometry shroud and show that large performance gains can be made with such a shroud.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Variable Geometry Shrouds Shrouded Propellers Propulsive Systems						

Security Classification